A COMPARISON OF PARTICULATE MATTER (PM10) IN INDUSTRIALLY EXPOSED AND NON EXPOSED COMMUNITIES

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DECLARATION

I, GONASAGREN MOODLEY declare that this is my own work. It is being submitted as a part requirement for the Degree of Master of Public Health, at the Nelson R Mandela School of Medicine, University of KwaZulu Natal, Durban, South Africa. This work has not been submitted previously to this or any other University.

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LIST OF ACRONYMS AND ABBREVIATIONS

DSIB	Durban South Industrial Basin
PM	Particle Matter
µg/m³	Micrograms per cubic meter
°C	Degrees Celsius
SDHS	South Durban Health Study
PM10	Particle matter < 10 micrometers
QA	Quality Assurance
%	Percentage
QC	Quality Control
m/s	Meters per second
µg	Microgram
AMIS	Air Management Information System
NAAQS	National Ambient Air Quality Standards
US/USA	United States of America
WHO	World Health Organisation
µm	Micrometers
TEOM	Tapered Elemental Oscillating Microbalance
US-EPA	United States-Environmental Protection Agency
m	Meters
AQMS	Air Quality Management system
N	Number
<	Less Than
>	Greater Than
DEAT	Department of Environment Affairs and Tourism

SA	South Africa
SANS	South African National Standards
vs	Versus
SPSHS	Settler's Primary School Health Study

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ABSTRACT

BACKGROUND

For many years, the Durban south community has raised concerns about ambient air pollution including particulate matter. The Durban South Industrial Basin (DSIB) may be high risk for exposure to significant levels of PM10 due to its geographic relationship with two major petroleum refineries, together with a pulp and paper manufacturing facility. While potential sources of elevated levels of PM10 in the south are industrial, the north is likely to be exposed to controlled burning of vacant fields and use of biomass fuels, particularly in informal settlements.

Adverse health effects from particulate matter (PM) were well documented by extensive epidemiological observations by animal and human studies, following laboratory exposures. Studies across a variety of environmental settings have demonstrated a strong association between ambient air particulate matter (PM10) and cardiopulmonary morbidity and mortality. Studies have reported that particulate matter is associated with adverse health effects resulting from inflammatory responses in the lower respiratory tract. Exposure to particulate matter may increase the risk of lung cancer. Some studies suggested that small temporal increases in ambient particulate matter are sufficient to cause health impacts. Other studies attributed strong seasonality to temperature inversions associated with temperature changes. Studies also illustrated the impact of temporal variation on PM10 levels across regions.

OBJECTIVES

The main objectives of this study were to determine and compare the levels of ambient PM10 in industry exposed and non-industry exposed communities, to determine temporal variation and to make recommendations.

METHODS

This study focused on determining the 24-hour ambient PM10 levels in the Durban south community. The PM10 levels in Durban south (industry exposed) were compared with the PM10 levels in an area north of Durban (non-industry exposed).

Relevant data obtained from the monitoring program of the South Durban Health Study (SDHS) was reviewed for the purposes of this study. The different techniques used to measure PM10 are gravimetric sampling and tapered elemental oscillating microbalance (TEOM). Both methods were used to collect PM10 data.

The data comprised of quantitative and categorical variables. The dependent variable was the PM10 values and the independent variable was the sampling sites. Non-parametric tests were used to analyse the data.

RESULTS

PM10 was recorded in all sites in north and south areas. The levels varied across all sites. Both the north and south areas recorded high PM10 values at regular intervals. No particular trend was observed when the 24 hour PM10 concentration was compared against the standard. All sites recorded medians that were generally in the region of 40-50$\mu g/m^3$. The site with the highest median (51.4$\mu g/m^3$) was Assegai. Briardale recorded the lowest median (34.9$\mu g/m^3$). Exceedances of the South African National Standard code 1929 maximum 24-hour concentrations of 75$\mu g/m^3$ were observed across all sites. Overall there were 163 (16.7 % of all samples) exceedances, and these ranged widely between the various sites, with no particular regional trend.

Overall June experienced the highest PM10 values. No differences in seasonal trends were observed in north and south.

CONCLUSION

On average the levels of PM10 do not exceed national or international standards. The findings did not reveal any statistical difference in exposure levels between the industry exposed and non-industry exposed areas.

CHAPTER ONE

1. INTRODUCTION

1.1 BACKGROUND

The Durban South Industrial Basin (DSIB), located within KwaZulu-Natal was the result of historically poor land use planning, coupled with racially discriminating policies of the apartheid era. In this area there is a mix of heavy and light industry, including two large petroleum refineries, a paper mill and major road networks. The Durban south population of approximately 200 000 live in 25 designated suburbs, most of which have been previously regionalized by race. The geography of Durban south is best described as a basin with low-lying topography located adjacent to the coast. This area is bounded by Bluff ridge on the southeast and Berea ridge in the northeast. Inversion is a phenomenon also commonly experienced in Durban south. The cold weather patterns and low temperatures during winter months exacerbate this phenomenon. During temperature inversions polluted air rises in the layer in which the temperature gradient is reversed and thus the concentration of pollutants in this layer increases. These conditions result in poor dispersion of pollutants and cause the pollutants to remain in the atmosphere for long periods. According to the eThekwini Air Quality Monitoring Network annual report for 2004, North Easterly and South Westerly wind directions are the prevailing wind directions in Durban south. Wind speeds in the 2.1 to 6m/s range appear to be the most common, with strong winds up to 12m/s occurring primarily in the autumn and spring months. [1]

The area has been reported to have a high unemployment rate, with a population in excess of 200,000 people, approximately 52% of the population is not economically active [2]. In recent years the DSIB has received much media attention as a result of the outcry and community action in response to the escalating concerns of pollution.

For many years, the Durban south community has raised concerns about ambient air pollution including particulate matter.

All stakeholders in Durban south: Government, industry, and the community have recognized the need for reliable data on levels and sources of ambient air pollutants [3].

The DSIB is at high risk for exposure to significant levels of PM10 due to the presence of two major petroleum refineries, together with a pulp and paper manufacturing facility and other smaller industries, as depicted by the yellow pins in figure 1. These facilities have relatively short emissions stacks, between 50 metres and 100 metres, and there is also a lack or ineffective emission control devices on the stacks [3]. The area is in close proximity to major arterial road network. This poses additional risk of exposure to PM10 from industrial and passenger vehicle emissions as well as from other major industries and the Durban International Airport. Interspersed within this area are schools indicated by the blue pins in figure 1.

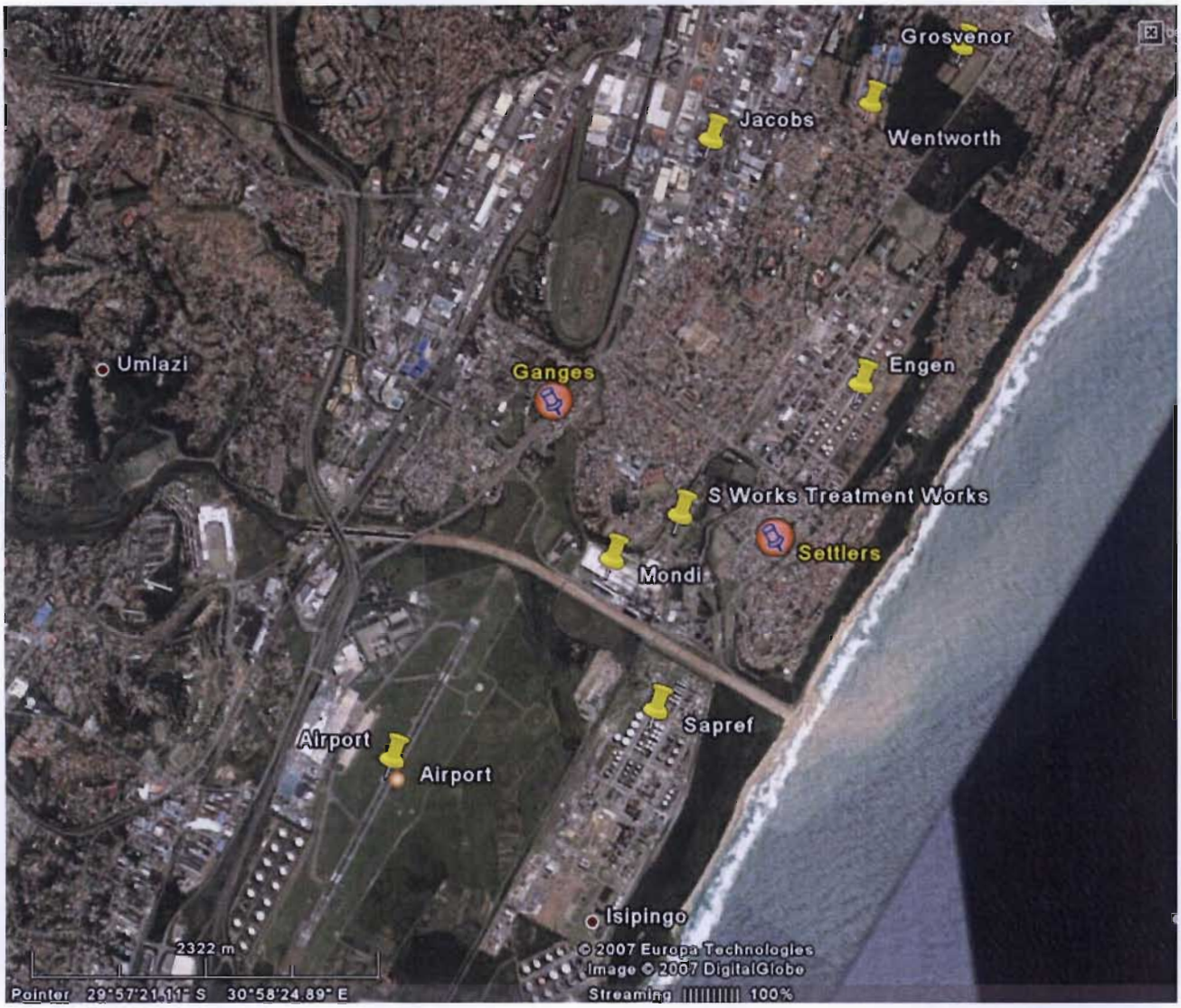

Figure 1. Aerial photograph of DSIB showing major industries and schools.

The eThekwini Air Quality Monitoring Network 2005 annual report recorded annual averages of 46.4$\mu g/m^3$ for 2004 and 43.1$\mu g/m^3$ for 2005. Both these values exceeded the South African National Standard (SANS) annual limit value for PM10 of 40$\mu g/m^3$.

Adverse health effects from particulate matter (PM) are well documented by extensive epidemiological studies including animal and human studies following laboratory exposures. Particulate pollution represents a substantial public health concern and is supported by remarkable consistency of positive findings across different study techniques, geographies, weather conditions, particle sources, as well as the coherence seen across a wide range of health effects and outcome measures [4]. A study focusing on particulate emissions, conducted in early 2002 at Settlers Primary School in Merebank provided strong evidence that ambient air pollution exposures are associated with acute changes in health status among students with moderate to severe asthma [3]. This study is discussed further in the literature review.

No studies have been undertaken comparing levels of particulate matter in the DSIB to other areas within the eThekwini Municipality. The current study was undertaken by reviewing the PM10 dataset collected during a broader study known as the South Durban Health Study (SDHS). The SDHS study was undertaken from May 2004 to September 2005 with PM10 data collection conducted over a 24-hour period. PM10 was monitored in schools located south of Durban (industrially exposed) and north of Durban (non-industrially exposed). The SDHS used different air samplers to monitor PM10. The monitoring sites and samplers are described later.

The findings from the current study provide a better understanding of the sources of particulate matter in both, Durban south and north communities. While potential sources of elevated levels of PM10 in the south are industrial, the north is likely to be exposed to control burning of vacant fields and use of biomass fuels, particularly in informal settlements. Industries have denied that their operations contribute, proportionally higher than non industrial sources, to the PM10 levels in the exposed communities in the DSIB.

Some of the possible non industrial sources of PM10 Durban south include traffic and use of biomass fuels. In view of the above discussions this study was proposed in order to provide a better understanding of PM10 emissions in the DSIB, a predominantly industrial exposed area, in comparison to a community with relatively low industrial exposure.

1.2 RESEARCH HYPOTHESIS

The ambient level of PM10 is higher in Durban south (industrial exposed) than in the Durban north (non-industrial exposed).

1.3 AIM/PURPOSE

The purpose of this study was to compare the ambient exposures to PM10 in the Durban south communities of Merebank, Austerville, Bluff, and Lamontville with the Durban north communities of Newlands East, Newlands West and KwaMashu where the level of industrial activity is relatively lower.

1.4 SPECIFIC OBJECTIVES

1.4.1 To compare the levels of ambient exposure to PM10 among the Durban south communities and the comparative communities located in north Durban.

1.4.2 To determine the month-to-month temporal variation of PM10 levels, and the geographic differences of this variable among the communities in the south and among those in the north. PM10 levels would be compared to environmental health standards.

1.4.3 To make recommendations to improve the control of PM10.

1.5 OPERATIONAL DEFINITIONS

The following definitions are used solely for the purposes of this study.

1.5.1 **Sampling:** The collection of a representative sample of PM10 for analysis and testing.

1.5.2 **Sample:** The mass concentration of PM10 collected using a PM10 sampler over a 24-hour sampling period.

1.5.3 **Sampler:** An electrically powered equipment that draws ambient air at a constant volumetric flow rate into a specially shaped inlet and through an inertial size separator (impactor) for collection on a filter over a specified sampling period.

1.5.4 **Collocation:** The placement of a sampler (known as the test sampler) near a second sampler (known as the reference sampler). The reference sampler (gold standard) is considered to provide accurate results, based on its recognized and well documented performance. Comparison of results from the two samplers is used to estimate the precision and bias of the test sampler used in the study.

1.5.5 **Field Blank Filter:** New filters, selected at random, weighed at the same time that pre-sampling weights are determined for a set of filters and used for quality assurance (QA) purposes. These field blank filters are transported to the sampling site in the same manner as filters intended for sampling, were installed in the sampler, removed from the sampler without sampling, stored in their protective containers inside the sampler's case at the sampler's case at the sampling site until the corresponding exposed filters are retrieved, and returned for post-sampling weighing in the laboratory, where they are handled in the same way as an actual sample filter and reweighed as a quality control (QC) check to detect weight changes due to filter handling.

1.5.6 **Laboratory Blank Filter:** New filters that are weighed at the time of determination of the pre-sampling weight of each set of filters intended for field use. These laboratory filters remain in the laboratory in protective containers during the field sampling and are reweighed in each weighing session as a QC check.

1.5.7 **Microbalance:** A type of analytical balance that can weigh to the nearest 10 μg.

1.5.8 **Particulate Matter (PM):** Particulate matter, suspend in the atmosphere, having an aerodynamic diameter less than or equal to a normal 10 μg, as measured by a reference method recognized by the United States – Environmental Protection Agency (US-EPA).

CHAPTER TWO

2. *LITERATURE REVIEW*

Particulate matter has been extensively documented in the literature for being associated with health outcomes, particularly adverse respiratory health in susceptible populations. Other health outcomes include cardiac and reproductive outcomes. The following review details the nature of particulate matter, the reasons for its pathogenicity, the levels of exposure seen in different geographic locations, and the health outcomes associated with these exposures.

2.1 DESCRIPTION OF PARTICULATE MATTER

Particulate matter refers to airborne particles that may include dust, dirt, soot, smoke and liquid droplets [3]. Particulate matter smaller than 10 μm in aerodynamic diameter are emitted by sources such as cars, trucks, buses, factories, unpaved roads, stone crushing and wood burning; as well as natural sources, e.g. sea spray, pollen, dust and volcanic debris [3]. Combustion sources emit most of the smaller PM most associated with adverse health effects [3]. Particle matter is a heterogeneous classification of liquid and solid aerosols which includes anthropogenic emissions from fuel combustion (coal, oil, and biomass), transportation, and high temperature industrial processes [4].

Industries that are likely to produce PM10, in Durban south, include refineries; paper mill; chemical manufacturing and industries with fuel burning appliances. In refineries PM10 is emitted from furnaces, especially those using coke fuels, and from catalyst based processes such as the "cat cracker" unit. Soot particles are visible in the flare when the air supply is insufficient.

Soot particles produced from incomplete combustion consist of carbon and metal oxides while the particles generated from the catalyst processes contains catalyst fines [5].

Local concentrations of air pollutants depend upon the strength of their sources and the efficiency of their dispersion. Day-to-day variations in concentration are more affected by meteorological conditions than by changes in source strengths. Under some conditions both factors may play a part: in cold, still weather, dispersion is reduced whilst production is increased by the increased use of domestic space heating. Wind is of key importance in dispersing air pollutants: concentrations being universally related to wind speed for ground level sources. Temperature inversions are of great importance in controlling the depth of the layer of air adjacent to the ground in which pollutants are mixed [6]. Seasonal variations and synoptic conditions are known to have a significant influence on ambient PM10 concentrations on a regional scale. Traffic contributions can often be underestimated.

Topography, although not included in this study, is also known to play a role, as elevated monitoring sites record lower PM10 concentrations than valley sites where dispersion is relatively poor [7]. The spatial distribution and concentrations of the various urban air pollutants including PM10 vary considerably. Urban air pollutants can be a local phenomenon, with ambient concentrations at any particular location varying with local site geography, emission rate and meteorological dispersion factors.

The revised United States (US) Federal Reference Method for PM10 specifies that PM10 measurements shall be reported at conditions of local temperature and pressure. Under the previous PM10 standard, the Federal reference measurement principles required that all measurements be adjusted to standard temperature pressure [8].

2.2 METHODS TO MEASURE PM10

PM10 monitoring differs from the monitoring of gaseous pollutants. Current techniques that are used to measure the mass concentration of particles in air make use of particle size-specific sampling devices, such as PM10 and PM2.5.

Thus the mass of particles less than 10μm (PM10) diameter may be determined as an index of the mass concentration of particles that can penetrate into the human thorax [6]

The different techniques used to measure PM10 are gravimetric sampling and tapered elemental oscillating microbalance (TEOM). Gravimetric methods include a number of techniques that draw air across a filter for a specified period, typically 24-hours, and measure the mass by weighing the filter prior to and following the sampling period. The filter is preconditioned and reconditioned prior to weighing and reweighing. These include both high-volume sampling methods that have flows of around 1133 litres per minute and low-volume methods that have much lower flow rates. Samplers are operated strictly in accordance with manufacturer's specifications to avoid variations during operation [9].

The TEOM method provides a direct measure of the mass concentration of particles. The measurement is based on the frequency of mechanical oscillation of a tapered glass element. The element contains a filter upon which particles are deposited. Air is drawn through the analyzer at a rate of 16.7 litres per minute and 3 litres per minute of the air is passed across the filter. The TEOM sensing system is heated to drive off water and to minimize the effects of thermal expansion and contraction of the mass sensor. This heating also results in loss of volatiles including nitrates and low molecular weight organic compounds. The amount of material volatilized depends on the composition of the particulate aerosol and the temperature setting of the TEOM. This method is one of the more technologically advanced instrumentation systems. Its operation is computerised and can be interrogated remotely for information on status, filter loadings and general operation. The filter requires changing about once every 2-4 weeks depending on loading.

Data are also available at a 10-minute time resolution allowing detailed comparison with variations in concentrations of other contaminants and meteorological conditions [9].

The various PM10 monitoring techniques may not necessarily produce comparable measurements. Different sampling systems, operating procedures, filter media, and filter history may also potentially affect measurement equivalence.

2.3 GLOBAL TRENDS AND GUIDELINE STANDARDS

Innovations and industrial technologies play a significant role in pollution levels within communities. In Africa, the industrial sector is an important user of raw materials and a major contributor to air pollution [10]. Air pollution is a major cause of environmental health problem affecting developed and developing countries around the world. Increasing amounts of potentially harmful particles are being emitted into the atmosphere on a global scale, resulting in damage to human health and the environment. It is damaging the resources needed for the long-term sustainable development of the planet [6]. The concentrations of PM10 in ambient air of European countries and of the United States have been extensively discussed in the development of the World Health Organization (WHO) Air Quality Guidelines for Europe [6]. In Western Europe and North America efforts to control emissions of particulate matter, such as the control of human activities including fires, overgrazing, agricultural practice and mining have generally resulted in lower levels of particles in ambient air. In many European cities the annual average concentrations of PM10 are in the range 20 to 50$\mu g/m^3$ for ambient air. However, annual average concentrations in some cities in Eastern Europe and in some developing countries can be above100$\mu g/m^3$ [6].

In developing countries, by contrast, the concentrations of PM10 in ambient air are higher according to the main source of information on air quality in developing countries, the Air Management Information System (AMIS) set up by WHO for voluntary reporting of data by municipalities of the WHO member states [6].

According to the WHO the annual average PM10 levels ranged from 50-100$\mu g/m^3$ in the years 1995-1996 for a limited number of cities [6], reporting data to AMIS. The highest annual concentrations, exceeding 250$\mu g/m^3$, were observed in Calcutta and New Delhi [6]. Table 1 below illustrates the annual PM10 levels averages measured in different times between 1990 and 2002 [11].

Table 1: PM10 ANNUAL AVERAGES FOR VARIOUS COUNTRIES [11]

COUNTRY	CITY	PM10 ANNUAL AVERAGE($\mu g/m^3$)	YEAR OF MEASUREMENT
India	New Delhi	140	2002
India	New Delhi	123	2001
India	Hyderabad	85	2001
China	Beijing	110	1999
China	Guangzhou	75	2001
Taiwan	Taipei	50	Not Indicated
Bangkok	Thailand	43	2001
Korea	Seoul	82	2002
Korea	Pusan	45	1999
Philippines	Manila	63	1999
Vietnam	Hanoi	70	2002

About 24 million people in the US lived in areas not meeting the US-EPA National Ambient Air Quality Standards (NAAQS) for PM10 (150 $\mu g/m^3$ - 24 hour average) in 1995 [3]. This illustrates that the problem pertaining to PM10 is not unique to developing countries. Table 2 illustrates annual averages for some areas in certain cities in South Africa (SA) that monitored PM10 levels [12].

Table 2: PM10 ANNUAL AVERAGES FOR SOUTH AFRICAN CITIES [12]

CITY	REGION	PM_{10} ANNUAL AVERAGE($\mu g/m^3$)	YEAR OF MEASUREMENT
Cape Town	Khayelitsha	56.76	2000
Cape Town	City Centre	23.10	2000
Cape Town	Goodwood	34.69	2000
Cape Town	Bellville South	33.02	2000
Johannesburg	Newtown	61.10	2001
Johannesburg	Alexandra	44.00	2001
Johannesburg	Randburg	46.00	2001
Durban	Wentworth	39.1	2004
Durban	Ganges	46.4	2004
Durban	City Centre	38.1	2004
Durban	Congella	37.6	2004
Durban	Ferndale	39.7	2004
Durban	Merebank	40.0	2004
Vaal Triangle	Sasolburg	57.00	2004
Vaal Triangle	Bertha Village	86.33	2004
Vaal Triangle	Orange Farm	64.55	2004

The US-EPA stipulates that the national 24- hour ambient air quality standards for PM10 shall be150$\mu g/m^3$ and the annual average it shall be 50$\mu g/m^3$ [13].

The Department of Environmental Affairs and Tourism (DEAT) has embarked on a continuous process to set guidelines values for PM10. Currently the guideline values for PM10 are prescribed in the South African National Standards (SANS) code 1929 [14].
On 9 June 2006 DEAT published ambient air quality standards for common air pollutants including PM10 (Government Notice 528) for public comment in accordance with the National Environmental Management: Air Quality Act, 2004.

The annual limit values for PM10 are the same as those stipulated in SANS code 1929. These values have been adopted as the ambient PM10 air quality standards for SA.
For the purposes of this research the SANS guidelines values will be used to evaluate the data. Table 3 provides some international standards including SA.

Table 3: INTERNATIONAL AIR QUALITY GUIDELINES FOR PM10 ($\mu g/m^3$)

	Maximum 24-hour Concentration ($\mu g/m^3$)	Annual Average Concentration ($\mu g/m^3$)
South Africa	75*	40*
United States EPA	150	50
WHO	-	50
Thailand	120	-
New Zealand	120	-
Korea	-	80
U.K	50	-
Bangkok	-	120

* SANS Code 1929

2.4 PREVIOUS STUDIES

There is a substantial body of epidemiological, toxicological and clinical evidence linking exposure to ambient PM10 with increased respiratory related morbidity and mortality. More recent epidemiological studies have confirmed that short-term exposures to ambient PM10 are associated with increases in mortality, emergency department visits, hospitalizations, medication use, asthma symptoms, respiratory infections, chronic bronchitis, and decreases in lung function [15]. In terms of PM10 guidelines values and standards, short term exposures relates to 24-hour exposure.

Numerous investigations studying multiple populations across a variety of environmental settings have demonstrated a strong association between ambient air particulate matter (PM10) and cardiopulmonary morbidity and mortality. Particulate matter is an important public health hazard that makes a significant contribution to the total burden of disease and death in populations across the world.

A growing body of research suggests that particulate matter is associated with adverse health effects resulting from inflammatory responses in the lower respirator tract and may increase lung cancer [16].

Yeatts K et al investigated whether markers of airway and systematic inflammation, as well as heart rate variability in asthmatics, change in response to fluctuations in ambient particulate matter.

Twelve adult asthmatics, living within a 30 mile radius of an atmospheric monitoring site in Chapel Hill, North Carolina, were followed over a 12 week period. The results suggest that small temporal increases in ambient particulate matter are sufficient to sufficient to increase cardiopulmonary and lipid parameters in adults with asthma [17].
Studies have also shown that patients suffering from asthma and chronic obstructive pulmonary disease suffer an increase in symptoms when levels of pollutants are raised [6]. Acute health effects also include increased daily mortality, increased rates of hospital admissions for exacerbation of respiratory disease, fluctuations in the prevalence of bronchodilator use and peak flow reductions [6].

Health effects relating to long-term exposure to PM10 include mortality and other chronic effects such as increased rates of bronchitis and reduced lung function. Two cohort studies in the United States suggest that life expectancy may be 2-3 years shorter in communities with high level of PM10 than in communities with low PM10 levels.

Numerous studies have shown a strong association between daily mortality and PM10, but the effects of season have not always been well characterized [18]. One study assessed the short term association between mortality and PM10 across seasons in a relatively highly polluted region in Europe. The study was conducted in Belgium, from January 1997 to December 2003. Data was analysed across warm versus cold periods of the year (April-September versus October-March).

The results show significant ($p<0.001$) interaction between PM10 and period of the year in relation to mortality [18]. This illustrates the impact of seasonality on PM10 particulate pollution.

The Settlers' Primary School Health Study (SPSHS) involved learners and teachers of a school located in the vicinity of the two major petroleum refineries, the paper mill and the wastewater treatment plant in Durban south [3]. This study provided evidence that ambient air pollution exposures including PM10 are associated with acute changes among the participants with moderate to severe asthma. The study used a TEOM with a PM10 inlet to measure particle matter. During the study period (19 April to 6 May 2001), PM10 was measured on a 24-hour (noon to noon) cycle. Samples were collected on a filter followed by gravimetric determination. Comparison of filter and TEOM data showed high correlation ($r=0.95$) and good agreement [3]. The monthly averages for PM10 from November 2000 to April 2001 in the SPSHS showed fairly constant levels ranging from 24$\mu g/m^3$ to 30$\mu g/m^3$ and an increase in May 2001 to 55$\mu g/m^3$. This increase may be due to temperature inversions associated with seasonal and temperature changes. The study reported that PM10 levels were highest during the daytime and early evenings, particularly from 07h00-09h00 and 20h00-21h00. The study recorded an average of 29$\mu g/m^3$ during the 3 week study period. Although this was not a true annual average it did not exceed the Department of Environmental Affairs and Tourism guideline value of 60$\mu g/m^3$ and the more recent SANS 1929 annual limit value of 40$\mu g/m^3$. The United State National Ambient Air Quality Standards and the World Health Organization guideline values were also not exceeded. The SPSHS reported that students at Settler's School were significantly more likely to report lower respiratory symptoms, including cough, chest congestion and wheeze. The study also reported that increased ambient air pollution levels, mainly respirable particulates, have shown to precipitate symptoms of asthma.

Chit-Ming Wong *et al* undertook a study to determine if the effects of air pollution on daily hospital admissions for respiratory and cardiac disease are consistent between Hong Kong and London [19]. The environmental settings and lifestyle are different in both cities.

Daily average 24-hour concentrations of PM10 were collected from background monitoring stations in each city. Only stations that were able to provide data for 75% or more days during the study period were used in the study. A daily concentration was accepted as valid if more than 17-hour measurements were made over a 24-hour period. The study used a statistical approach that closely followed the one adopted by the Air Pollution and Health: a European Approach-2 study [19]. PM10 emissions in London were predominantly from traffic (83%). In Hong Kong PM10 was 61% from traffic and 33% from power generation. The overall regional concentrations of PM10 levels in Hong Kong were almost double those in London (46.8$\mu g/m^3$ versus 24.8$\mu g/m^3$). This study showed differences in the effects of PM10. In Hong Kong, the effects were stronger in the cooler months, whereas they were stronger in the warmer months in London [19]. This clearly demonstrated the evidence of temporal variation in the effects of PM10.

The South Coast Air Quality Management District, in Southern California, conducted a 1-year special particulate monitoring study from January 1995 to February 1996. This monitoring data indicated that high PM10 concentrations were observed during the months of October (range 120$\mu g/m^3$– 60$\mu g/m^3$), November (range 115$\mu g/m^3$ – 80$\mu g/m^3$), and December (range 50$\mu g/m^3$ – 95$\mu g/m^3$) with November reporting the highest in all sites, except for one site where October reported the highest (120$\mu g/m^3$). The high PM10 concentrations during these months were attributed to stagnant and high wind conditions. During the rest of the year PM10 concentrations gradually increased from January to September (range 20$\mu g/m^3$ - 85$\mu g/m^3$). Monthly PM10 concentrations generally ranged from 20 to 120$\mu g/m^3$. In this study the highest PM10 was recorded in November (226.3$\mu g/ m^3$) while the lowest PM10 concentration was recorded in February (19.5$\mu g/m^3$) [20]. This further illustrates the impact of temporal variation on PM10 levels across regions.

The assessment and management of the air quality at Lakhanpur area in Orissa State in India was conducted by Chaulya et al. The 24-hour average concentrations of PM10 were monitored during 1-year period.

Samplings were done at a regular interval throughout the year at 13 monitoring stations in the residential areas and four monitoring stations in the mining/industrial areas. The 24-hour average concentrations for PM10 ranged from 102.5$\mu g/m^3$ to 425.6$\mu g/m^3$ for the industrial areas and 40.8$\mu g/m^3$ to 171.9$\mu g/m^3$ for residential areas [21]. It is plausible that the impact of industrial activity contributed significantly to the extremely wide range reported for industrial areas. Maximum concentration of PM10 was observed at the mining site. This study reported that PM10 gradually decreased with distance from the industrial areas especially the mining sites. It was also reported that the 24-hour and annual average PM10 concentrations exceeded the respective standards set in the NAAQS protocol at most residential and industrial areas. Temporal variations were evident in this study.

PM10 in a ceramic industrial area in East Spain was studied from April 2002 until December 2005. PM10 levels were measured at rural, suburban and urban areas, all influenced by the ceramic industry. Annual average for PM10 levels varied between 27$\mu g/m^3$ and 36$\mu g/m^3$ for the study period [22]. Evaluation of PM10 data from the suburban monitoring sites during the study period showed a clear decrease of PM10 levels since the beginning of 2002. The study attributed this decrease to the gradual implementation of PM10 emission abatement techniques in a significant number of ceramic factories. Summer PM10 peaks and winter minima were evident, which was due to greater atmospheric mixing in summer favouring transport of pollutants from urban or industrial hotspots towards rural areas. The study expected higher urban PM10 levels in winter; however the levels reported in summer were relatively high due to a number of factors such as low rainfall, inland transport of pollutants by sea and African dust intrusions. The maximum PM10 levels reported in the study were attributed to typical anti-cyclonic scenarios with thermal inversion episodes resulting in the accumulation of regionally emitted pollutants [22].

A comparative PM10 source contribution study at rural urban and industrial sites in Eastern Spain was undertaken by Rodriguez *et al.* In this study, 340 PM10 samples were collected over 16 months at rural, urban curbside and industrial backgrounds affected by the emissions from ceramic manufacture and other sources.

On a regional scale, the main PM10 emissions were dust emissions derived from power generation, vehicle exhaust emissions and marine aerosol. At the industrial site additional sources were identified (ceramic production, petrochemical emissions and bio-mass burning). The results indicated that PM10 annual average concentrations at the urban and industrial sites (49.5$\mu g/m^3$) were higher than those at the rural site (22.0$\mu g/m^3$) [23]. The contributions of urban road dust and dust from ceramic productions are evident in these concentrations respectively. This study provided a clear indication that PM10 concentrations are higher in exposed (industrial and urban) areas than non-exposed (rural) areas.

The seasonal variations of PM10 in residential and industrial sites were studied in an urban area of Kolkata, India [24]. The primary objective of this comparative study was to investigate seasonal and spatial variations of PM10 from November 2003 to November 2004. Monitoring sites were selected based on dominant activities of the area such as unplanned urbanization, uncontrolled vehicular density on gravel road space and industrial processes. The 24-hour average concentrations of PM10 for residential area were reported in the range of 68.2 – 280.6$\mu g/m^3$. The wide range reported could be attributed to local traffic conditions as the monitoring site was located in proximity to main roads. Seasonal variations and meteorological parameters may have also influenced the range. The 24-hour average concentrations of PM10 for industrial area were reported in the range of 62.4 – 401.2$\mu g/m^3$. The high particulate concentration at industrial area may be attributed to the heavy traffic flow, emissions from nearby industries, and re-suspension of dust from roads [24]. Here, again the seasonal variations and meteorological parameters may have also influenced the range. As expected higher PM10 concentrations were reported for the industrial area. This may be attributed to industrial emissions and pollution from automobile sources. The study reported a significant seasonal trend.

For the investigation of the seasonal variations of PM10, the year was divided into three periods, summer (March to June), monsoon (July to October) and winter (November to February), as per the regional meteorological considerations [24].

The study reported strong seasonality in the following order: winter > summer > monsoon. The maximum daily PM10 concentration was 401.2$\mu g/m^3$ during winter, while minimum value was 62.4$\mu g/m^3$ during monsoon. Winter to monsoon ratio was 1:6 and 2:3 for residential and industrial areas, respectively. Higher winter concentration was due to low wind speeds and low mixing height resulting in high residence time of the pollutants [24]. This is consistent with the inversion phenomenon experienced during the winter period. The study reported strong winds and good mixing height during summer. This resulted in lower PM10 concentration that winter. Minimum monsoon concentration was due to washout of the particles by rains.

2.5 SUMMARY

PM10 levels varied across different studies undertaken in different locations. The levels reported in the studies ranged from 24$\mu g/m^3$ to 425$\mu g/m^3$. Temporal and seasonal variations were the main factors that affected these levels. Higher maximum levels were generally reported in industrial settings which contributed significantly to the wide ranges reported in some studies.

CHAPTER THREE

3. *RESEARCH METHOLODGY*

This study focused on reviewing raw data obtained from the monitoring program of ambient PM10 for the purposes of the SDHS, which was conducted by the University of Kwa-Zulu Natal who successfully tendered for the study requested by the eThekwini Municipality. A primary focus on air pollution and disease outcomes was the key elements of the approach to the SDHS. Another key element of the study design was the development of a profile or 'snapshot' of the disease profile among a representative Durban south community sample, as well as a suitable comparison population elsewhere in Durban north. In order to achieve these objectives SDHS undertook monitoring of key pollutants including PM10 sampling in Durban south community (industrially exposed) as well as a comparison community north of Durban (non-industrially exposed).

The SDHS involved a representative selection of schools with a greater geographic coverage. Annexure 1 describes the approaches adopted by the environmental monitoring team of the SDHS in the collection of the PM data. The data collected by these techniques were subsequently analysed by the researcher of this study for purposes of the masters' dissertation. The researcher did not participate in the collection of the data however observations during fieldwork were undertaken.

3.1 LIMITATIONS OF THE SDHS DATASET

The following discusses the limitations of the SDHS dataset.

3.1.1 Variations in the laboratory environment during filter handing, pre- and post weighing of filters could create outliers in the dataset. The laboratory operated within standard operating procedures. A comprehensive QC/QA plan was developed which involved the deployment of laboratory and field blanks.

3.1.2 Data collection involved a great deal of filter handling during field work. This could have resulted in filter contamination. Standard operating procedures were developed and implemented during filter deployment and fieldwork. This included the deployment of field blanks. Filter contamination during handling could have resulted in extremes values. The dataset was checked for extreme values.

3.1.3 Various equipment types were used for PM10 data collection. These included high and medium volume sequential samplers, low volume Partisol (2000) sampler and TEOM. These variations could have resulted in measurement bias. Prior to deployment of the various samplers a collocation study was conducted to compare performance of the different samplers against a reference method. This aspect is discussed later

3.1.4 Variation in operating conditions of the equipment could have resulted in negative values in the dataset. All samplers were calibrated prior to deployment. The flow rates of the samplers were monitored during fieldwork and were reset when necessary. The dataset was checked for negative values.

3.2 METHODS USED FOR THE CURRENT STUDY

As indicated earlier this study focuses on reviewing data obtained from the monitoring of ambient PM10 undertaken during the SDHS as part of the environmental monitoring programme. Raw PM10 ambient monitoring data was obtained from the SDHS. The raw data was obtained as unclean data i.e. data with outliers, extreme positive values and negative values. The data obtained was in electronic format using Microsoft Excel programme. The total (n) number of samples reviewed was 978.

3.2.1 Study Design

This study was a comparative community exposure assessment of PM10 levels in different residential areas in Durban. This assessment was intended to describe exposure for participants in the larger epidemiological study.

3.2.2 Data Management

Data obtained from the SDHS included *inter alia* information relating to the sampling site, filter and sampler used, details of the sampling duration (start and end), laboratory filter weighing and laboratory conditions during filter weighing. The relevant information was extracted and used for the purposes of this study. The variables relating to date of sample and PM10 concentrations were obtained directly from the SDHS dataset. The other variables relating to site reference number, sampling month, area (north/south) and standard exceeded are new variables. The actual PM10 concentration was expressed as a value in $\mu g/m^3$ and was the key variable of interest. In order to get a representative sample PM10 was collected over 1440 minutes for the 24-hour sample duration with the sampler set at a predetermined flow rate. This may not be achieved in instances of equipment failure. This was considered during the SDHS data collection. Values below 90% (1296 minutes) of the sample duration and values <10% of the sample flow rate was considered as not being representative and was rejected by the SDHS. Data relating to date of sampling, sampling site and PM10 values were transferred electronically from the SDHS database. This information was captured directly from the SDHS database in the relevant fields created in the data collection sheet (Annexure 2).

The date fields captured the date the sample was obtained and was expressed in dd/mm/yyyy format in order to ensure uniformity during data capturing and to avoid errors and, contradictions during data analysis. The site reference number field refers to the code allocated for each sampling site as follows:

Nizam – 1, Assegai – 2, Dirke Uys – 3, Entuthukweni – 4 (south sites), Ferndale – 5, Briardale – 6, Ngazana – 7 (north sites). The sampling month makes reference to the month the sample was obtained. This was coded according to the month of the calendar year for example May – 05.

The North /South fields refers to the geographical locality of the sampling site and was coded as North – 1, South – 2. The PM10 value was the actual daily mean recorded for the site on the specified date and was expressed in $\mu g/m^3$.

This value was compared with the guideline value. If the guideline value was exceeded it was indicated as Yes – 1 and No – 2. This was a new variable that was created. The PM10 values were compared against SANS code 1929 to determine exceedances of the guideline value.

This data base was subjected to accuracy checks against the SDHS dataset. Data was entered twice to ensure consistency and the entries were manually checked against the SDHS. No discrepancies were observed. Back up systems were used to protect data.

3.2.3 Data Analysis

SPSS version 13 statistical computer software programme was used to analyse data (SPSS Inc. Chicago, Illinois, USA). The data comprised of continuous and categorical variables. The continuous variable was PM10 and the categorical variables included area (north/south), and standard exceeded (yes/no). The dependent variable was the PM10 values and the independent variable was the sampling sites. For the purposes of data analysis the quantitative variables were checked for normality using skewness statistic and the standard error, as well as the histogram plots. If the skewness statistic was more than twice the standard error, skewness was confirmed.

Prior to conducting any formal statistical analysis exploratory data analysis was undertaken. Frequency tables for categorical/binary variables and histograms for quantitative variables were used to summarise observations. As expected for dust exposure data, the data was likely to be skewed. Therefore non-parametric tests were used to analyse the data. Non-parametric methods are an alternative set of statistical techniques for analysing numerical data that make no assumption about the underlying distribution, for example the normality of the data [25]. The univariate analysis comprised of descriptive statistics that involved calculating the medians, quartiles, maximum and minimum values and the range. Box plots were used to display the data in a summarised form. The median (or 50^{th} percentile) is that value which divides the sample values, ordered from small to large, in half, that is, half the values lie above the median, the other half below. Quartiles divide the sample in quarters. The lower quartile is also called the 25^{th} percentile, and the upper quartile the 75^{th} percentile. The distance between the lower and upper quartile is called the inter-quartile range [26]. The range, which is the difference between the largest and smallest values, is the simplest measure of variation. Its disadvantage is that it is based on only two of the observations and gives no idea of how the other observations are arranged and between these two [25]. Box and wisker plots were used to identify outliers and extreme values. Outliers were PM10 vlaues that were 1.5 to 3 box lengths from the top or bottom edge of the box (interquartile range). Extreme points were PM10 values >3 box lengths from the top or bottom edge of the box. Data points indicating outliers and extreme values were included in the dataset. As non-parametric statistics were used these data points were not considered to be a problem since non-parametric statistics uses the rank of the data and not the absolute value. Bivariate analysis was undertaken to determine statistical significance for measures of association. Kruskal-wallis non-parametric tests were used to compare median PM10 values and the median values of exceedance of the standard between the seven sites. Where a significant difference was detected using Kruskal-Wallis tests, Dunn's post hoc tests were performed using Graph Pad Instat version 3.05 (2000) to determine where the significance lay.

Mann-Whitney tests were used to compare median PM10 values and median values of exceedance of the standard between north and south areas. Pearson's chi square tests were used to compare the proportions of sites and areas with the standard. A p value of <0.05 was considered as statistically significant. By cross tabulating the standard exceeded (yes/no) variable with the area (north/south) and site, Chi square test was undertaken to assess whether there was an association between exceedance and area or site.

3.3 INSTITUTIONAL AND ETHICAL CLEARANCE

In view of the fact that this research was based on sampling and monitoring results from the SDHS it was necessary to obtain written confirmation from the principle investigators to the effect that the study had been given ethical approval. Written permission had been obtained from the principal investigators to use a sub-set of the SDHS data for purposes of this study. The research proposal for this study was submitted to the University of KwaZulu-Natal Ethics Committee for ethical clearance. The Ethics Committee subsequently approved the research proposal in writing (ref EXP040/06). Individual informed consent was not necessary, as there were no human subjects or individual participants in this study.

3.4 SUMMARY

This study focused on reviewing data collected during the SDHS. The study design was analytical observational study, with quantitative particulate data, and categorical representation of the geographic locations of the monitoring sites. Data analysis involved the initial cleaning to ensure that a sound dataset was available, excluding outliers and non-representative values. Analysis involved descriptive assessment of the data followed by bivariate analyses to assess for association between exposure levels and location. There were no human subjects involved in the study, hence no consent was necessary. Ethical approval was obtained.

CHAPTER FOUR

4. RESULTS

4.1 DESCRIPTIVE DATA

The data set arising from the South Durban Health Study comprised of 978 PM10 samples. In this study 3 areas were in the north (n=408) and 4 areas were in the south (n=570). The mean was 50.18 and the standard deviation was 31.3561. PM10 concentrations ranged from, 0.7$\mu g/m^3$ to 266.6$\mu g/m^3$.

Table 4 provides a breakdown of the number of samples obtained in each sampling month.

Table 4. NUMBER OF SAMPLES OBTAINED PER SAMPLING MONTH

SAMPLING MONTH	NUMBER OF SAMPLES PER MONTH
January	19
February	149
March	26
April	40
May	47
June	179
July	70
August	107
September	107
October	91
November	116
December	27
Total	**978**

The breakdown of the number of samples obtained in each community is detailed in table 5 below.

Table 5. NUMBER OF SAMPLES OBTAINED PER SAMPLING SITE AND TYPE OF SAMPLER USED

SAMPLING AREA	n	SAMPLER
Nizam	167	Low Volume Partisol 2000
Assegai	137	High Volume Sequential Sampler
Dirkie Uys	135	High Volume Sequential Sampler
Lamont	131	High Volume Sequential Sampler
Ferndale	139	TEOM
Briardale	131	Medium Volume Sequential Sampler
Ngazana	138	Medium Volume Sequential Sampler

The number of datasets obtained during the SDHS field sampling varied across the sampling areas and monitoring type. The TEOM had data capture rates exceeding 80%. The number of 24 hour filter-based samples ranged from 131 at Briardale to 167 at Nizam. These variances were due to many factors, including sampling errors and equipment malfunction. No data was available for data last due to sampling errors and equipment malfunction.

Summary statistics for the data analysed (over all the sites) is as follows:

N = 978

Mean = 50. 2$\mu g/m^3$

Median = 42.4$\mu g/m^3$

4.2 SITE BY SITE VARIATION

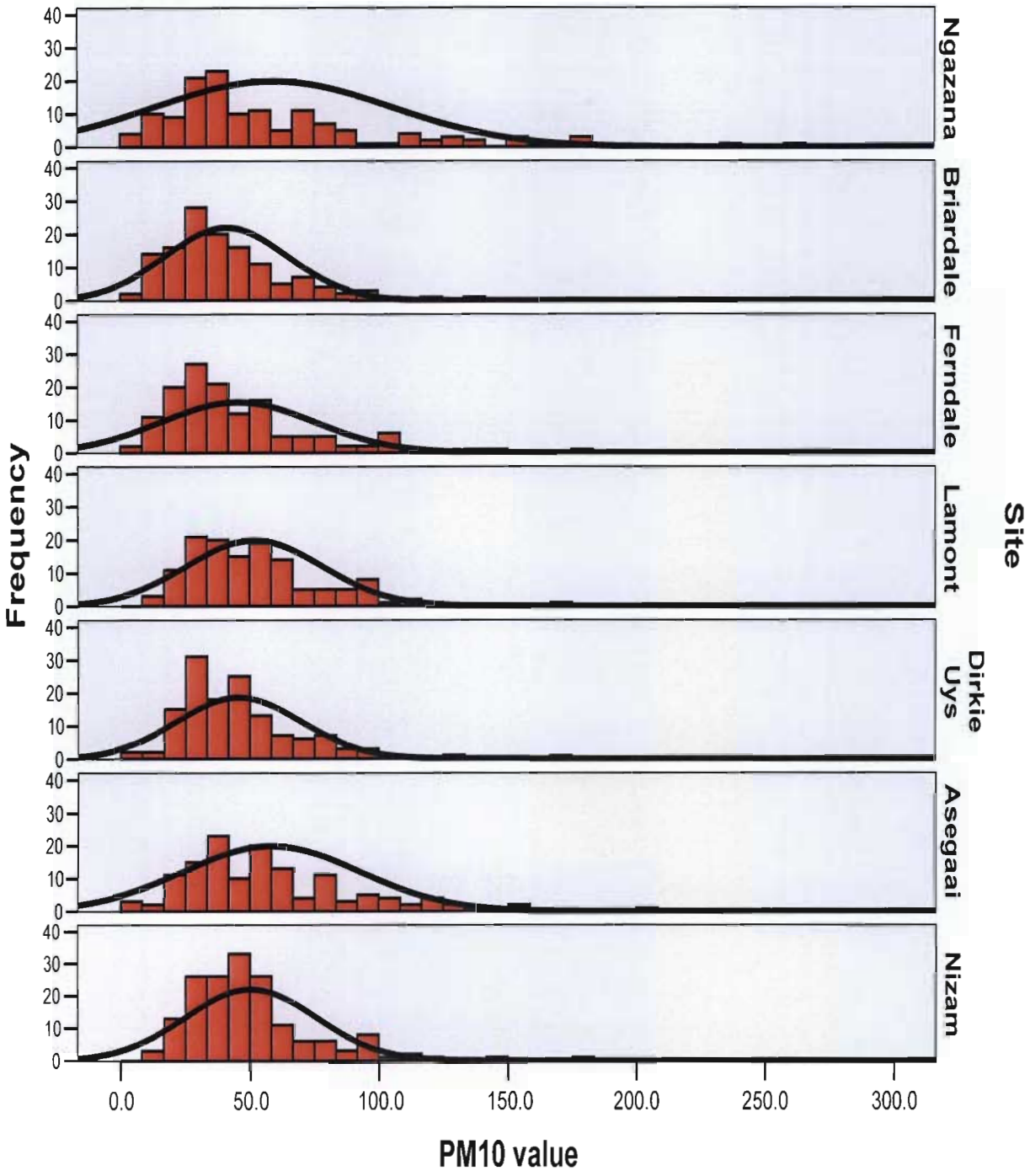

Figure 2. FREQUENCY DISTRIBUTION OF PM10 ($\mu g/m^3$) VALUES BY SITE

The frequency distributions (figure 2) of the dependent variable were asymmetrical and highly skewed to the right. This means that the results were positively skewed.

The site with the highest median (51.4$\mu g/m^3$) was Assegai. Briardale recorded the lowest median (34.9$\mu g/m^3$). The highest maximum (266.2$\mu g/m^3$) PM10 value recorded was Ngazana. The range (265.8$\mu g/m^3$) was also highest at this site. Ngazana recorded the lowest minimum (0.7$\mu g/m^3$) PM10 value (table 6).

Table 6: PM10 ($\mu g/m^3$) RESULTS PER SAMPLING SITE

Site	N	Median	Minimum	Maximum	Range
Nizam	167	45.9	14.0	179.4	165.4
Assegai	137	51.4	1.2	208.0	206.8
Dirk uys	135	41.5	1.4	170.6	169.1
Lamont	131	45.4	9.6	173.8	164.3
Ferndale	139	37.0	4.5	178.7	174.2
Briardale	131	34.9	1.9	133.8	131.9
Ngazana	138	42.9	0.7	266.6	265.8

All sites recorded medians that were in close proximity to each other. This was generally about 40-50$\mu g/m^3$ (figure 3). Outliers and extreme values were described at all sites, however, the most extreme values were recorded at Assegai and Ngazana, with values in excess of 200$\mu g/m^3$ and 250$\mu g/m^3$ respectively (table 6).

The Kruskal-Wallis test was undertaken to test for significant difference in median PM10 between the sites. There was a significant difference in median PM10 values between the sites (chi square= 37.5; $p<0.001$).

Dunn's post hoc analysis indicated Briardale was significantly different to Nizam, Assegai, Lamontville and Ngazana ($P<0.05$) Assegai was also significantly different to Dirkie Uys ($p<0.05$) and Ferndale ($p<0.001$).

No differences in median values were recorded between Briardale and Dirkie Uys; Briardale and Ferndale, and Assegai and Nizam; and Assegai and Lamont; and Assegai and Ngazana.

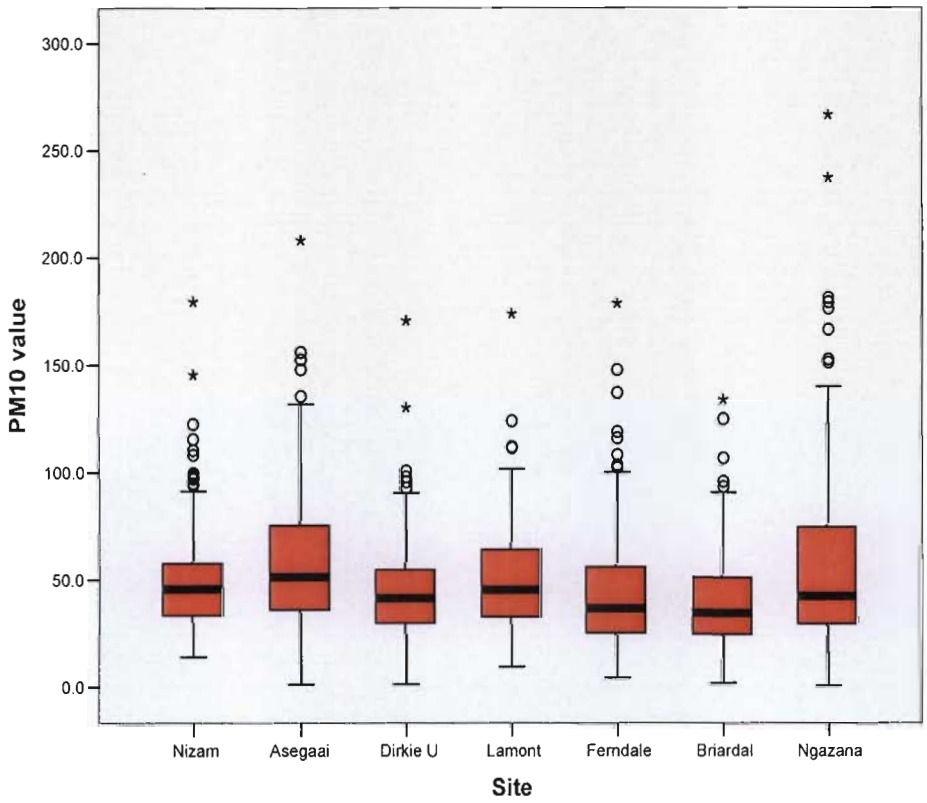

Figure 3: BOX PLOT ILLUSTRATING PM10 ($\mu g/m^3$) VALUES FOR ALL SITES

4.3 REGIONAL (NORTH-SOUTH) VARIATION

The median in the south ($45.7\mu g/m^3$) was higher than the median in the north ($38.1\mu g/m^3$) (table 7). The maximum ($266.6\mu g/m^3$) and minimum ($0.7\mu g/m^3$) values were recorded in the north. Using the Mann-Whitney test, there was a statistically significant difference between north and south ($p<0.01$).

Table 7: PM10 ($\mu g/m^3$) VALUES IN NORTH AND SOUTH

Area north/south	N	Median	Minimum	Maximum
North	408	38.1	.7	266.6
South	570	45.7	1.2	208.0
Total	978	42.4	.7	266.6

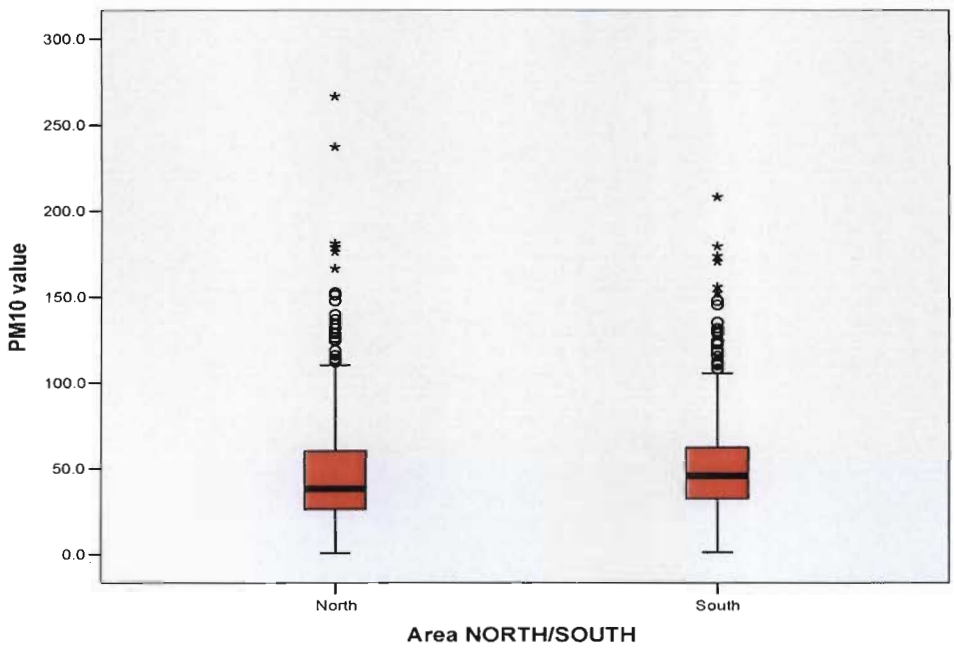

Figure 4: BOX PLOT ILLUSTRATING PM10 ($\mu g/m^3$) VALUES IN NORTH AND SOUTH

Extreme values and outliers were recorded in north and south. Higher extreme values (266.6$\mu g/m^3$) were recorded at Ngazana located in the north (figure 4).

4.4 EXCEEDANCES OF THE STANDARD

Table 8 shows the standard exceeded by the individual sampling site. The South African National Standard code 1929 which stipulates 75$\mu g/m^3$ as the maximum 24-hour concentration was used to assess exceedances at each site. Overall there were 163 (16.7 % of all samples) exceedances, and these ranged widely between the various sites, with no particular regional trend.

The highest number of exceedances (36 episodes [26.3 %]) was recorded at Assegai in Durban south. Ngazana in Durban north also recorded high exceedances (34 episodes [24.6 %]). The site with the lowest exceedances (11 episodes [8.4 %]) was Briardale in Durban north. The site with the lowest exceedances in Durban south was Dirkie Uys (16 episodes [11.9 %])

Table 8: PM10 ($\mu g/m^3$) STANDARD EXCEEDED BY SITE

Site	Standard exceeded		Total
	N	%	
Nizam	23	13. 8	167
Assegai	36	26. 3	137
Dirkie Uys	16	11. 9	135
Lamont	23	17. 6	131
Ferndale	20	14. 4	139
Briardale	11	8. 4	131
Ngazana	34	24. 6	138
Total	**163**	**16. 7**	**978**

Durban south had higher number of exceedances with 98 episodes (17.2 %) when compared to Durban north with 65 episodes (15.9 %). There was no significant association between area and exceedance (p=0.602). The possible explanation for the non-significant association was the two (2) sites with the highest percentage of exceedances were located in north (Ngazana) and south (Assegai) respectively. This diluted any differences between the areas.

4.5 MONTHLY VARIATION AND EXCEEDANCES

Table 9: MONTHLY PM10 ($\mu g/m^3$) VARIATIONS FOR NORTH AND SOUTH

SAMPLING MONTH	MEDIAN	MINIMUM	MAXIMUM	NUMBER OF EXCEEDN-ACES PER MONTH	NUMBER OF SAMPLES PER MONTH
January	34.6	15.6	48.3	0	19
February	30.1	11.7	85.1	2	149
March	38.5	25.3	76.0	1	26
April	41.0	18.3	67.6	0	40
May	71.8	24.4	152.6	21	47
June	75.1	24.7	266.6	90	179
July	56.1	1.2	237.2	20	70
August	46.4	1.4	122.6	16	107
September	39.0	1.9	137.1	5	107
October	40.8	15.5	131.9	7	91
November	38.1	.7	75.2	1	116
December	25.4	5.5	54.2	0	27
Total	42.4	.7	266.6	163	978

Table 9 reports the medians, minimum, maximum PM10 values and exceedances for all sites in north and south. The median (75.1$\mu g/m^3$) was highest in June. The maximum value (266.6$\mu g/m^3$) was also highest during this month. This pattern was similar for the months of May and July. The lowest median level was in the month of December (25.4$\mu g/m^3$). The period between May and July experienced the most number of exceedances, with June (90) reporting the highest. The north reported 65 exceedances and the south reported 98 exceedances.

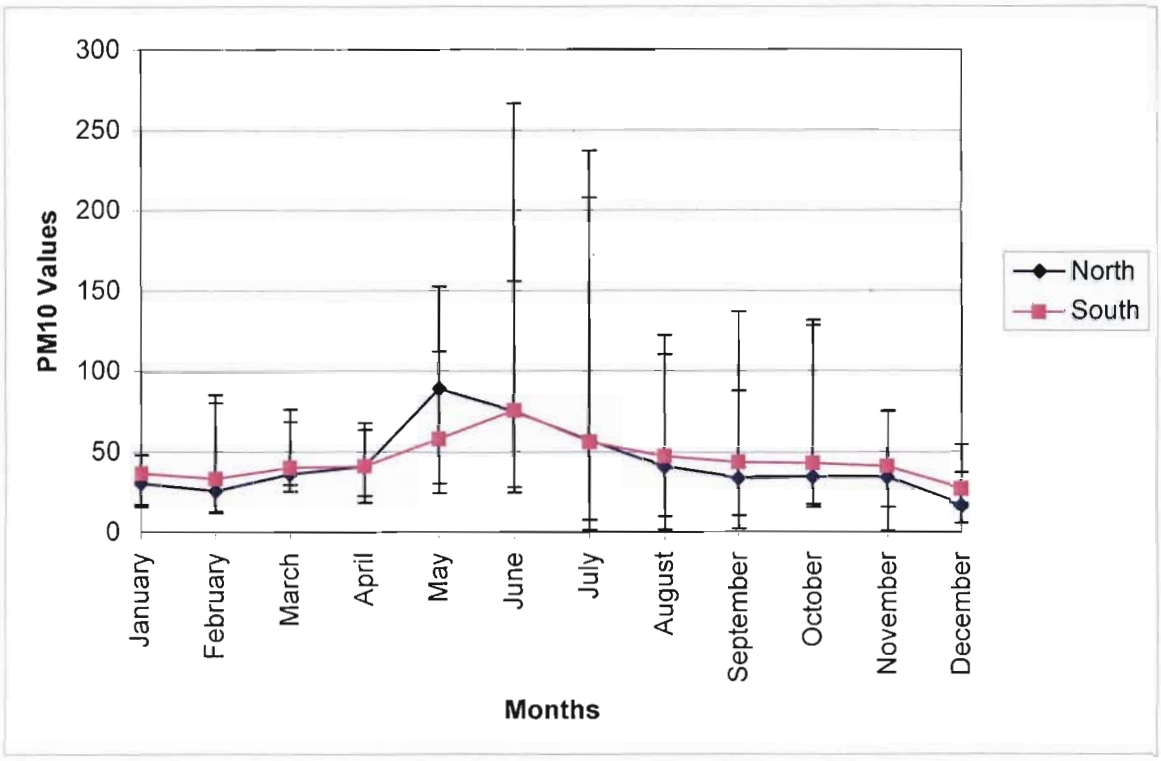

Figure 5: OVERALL PM10 ($\mu g/m^3$) VALUES PER MONTH

Overall the PM10 values recorded for north and south were similar in pattern for most months during the sampling period, except for May when the north experienced higher PM10 levels (figure 5). High maximum values were recorded for from May to July. This is typical of winter months.

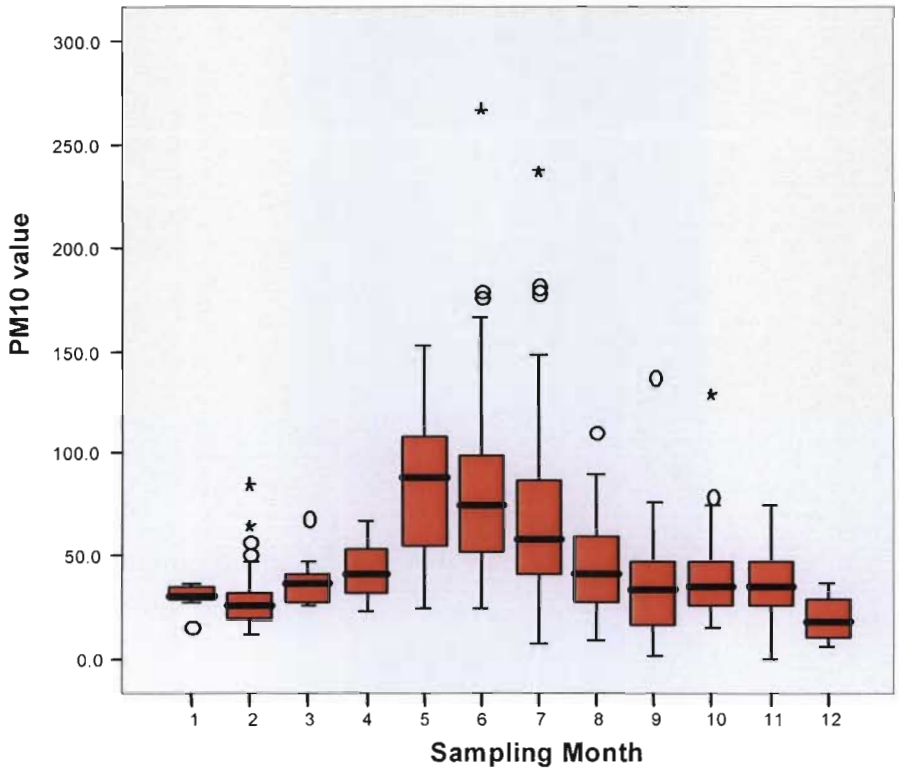

Figure 6: BOX PLOT ILLUSTRATING PM10 ($\mu g/m^3$) VALUES FOR NORTH

May recorded the highest median ($88.8\mu g/m^3$) in the north (figure 6). The highest maximum was recorded in June ($266.6\mu g/m^3$). July also recorded a high maximum value ($237.2\mu g$ m^3). The lowest minimum value was recorded in November ($0.7\mu g/m^3$). The temporal variation in the north is consistent with that of the south.

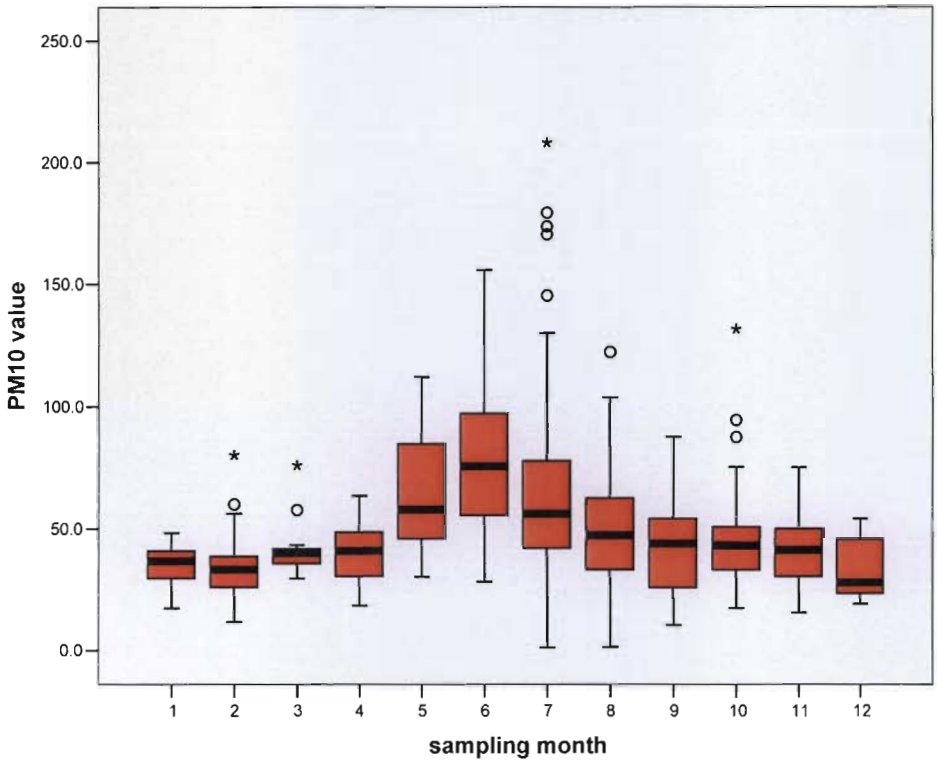

Figure 7: BOX PLOT ILLUSTRATING PM10 ($\mu g/m^3$) VALUES FOR SOUTH

June recorded the highest median ($75.6\mu g/m^3$) in the south (figure 7). The medians were also high in May ($57.9\mu g/m^3$) and July ($56.1\mu g/m^3$). The highest maximum was recorded in July ($208.0\mu g/m^3$). The maximums were also high in May ($112.3\mu g/m^3$) and June ($155.93\mu g/m^3$), as compared to the other months. The lowest minimum PM10 value was recorded in July ($0.7\mu g/m^3$).

4.6 EXCEEDANCES OF ANNUAL STANDARDS

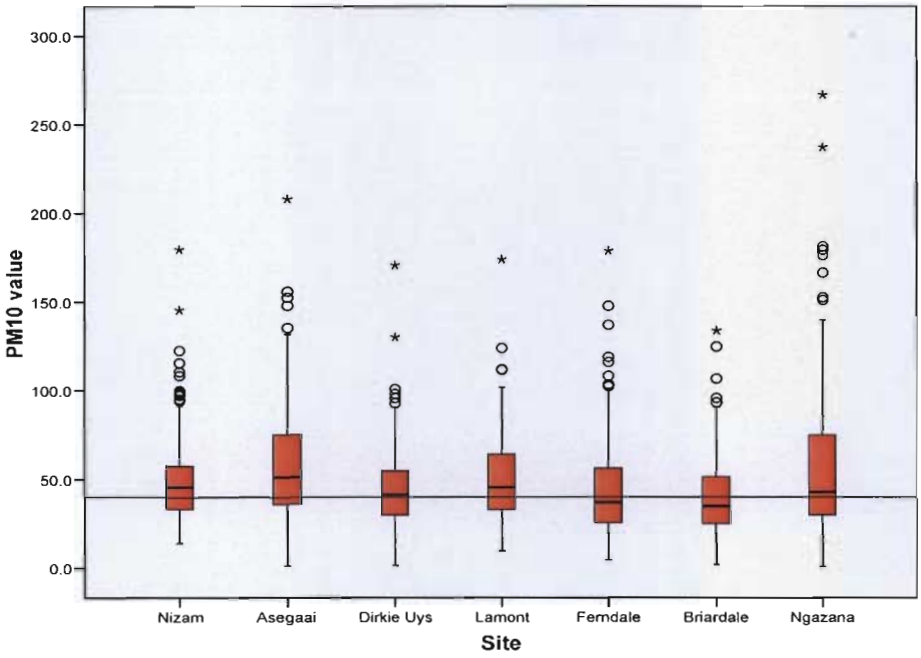

Figure 8: BOX PLOT ILLUSTRATING ANNUAL MEDIAN PM10 ($\mu g/m^3$) VALUES FOR ALL SITES

The South African National Standard code 1929 which stipulates $40\mu g/m^3$ as the annual average that should not be exceeded. This standard was used to assess annual exceedances for all sites in the north and south areas. Although the results show that the median PM10 for certain areas (Nizam, Assegai, Lamont, Dirk Uys and Ngazana) were higher than the standard value of $40\mu g/m^3$, and other sites (Ferndale and Briardale) were near this value, statistically the standard value was not significantly different to these sites. Figure 8 show that the standard value of $40\mu g/m^3$ were inside the inter-quartile range for all sites, therefore implying no statically significant difference between the sites.

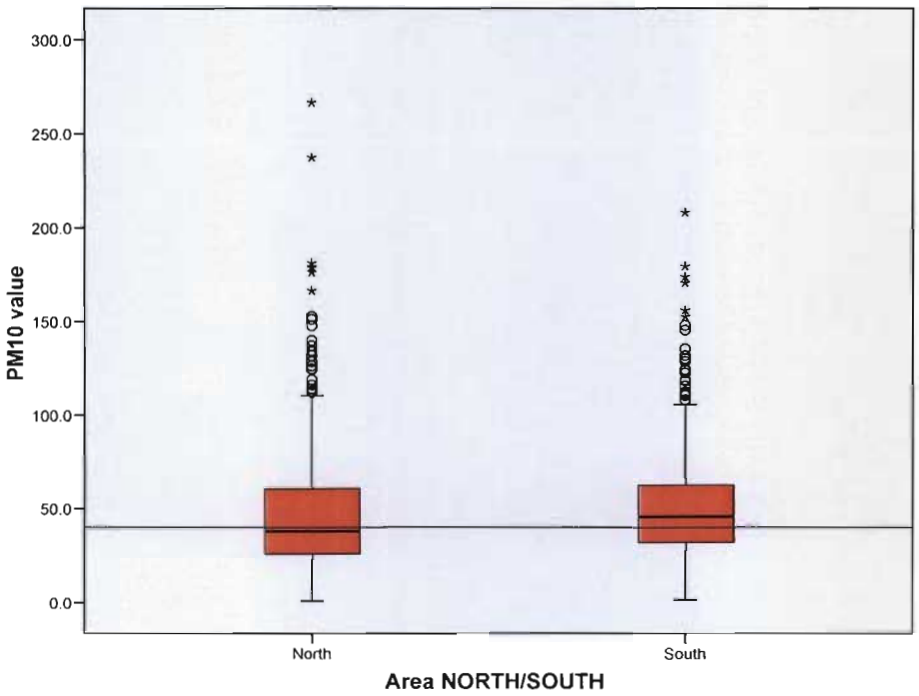

Figure 9: BOX PLOT ILLUSTRATING ANNUAL MEDIAN PM10 ($\mu g/m^3$) VALUES FOR NORTH AND SOUTH

Figure 9 shows that the standard value of $40\mu g$ m^3 was inside the inter-quartile range for both north and south sites respectively, therefore implying no statically significant difference between the sites.

4.7 SUMMARY OF RESULTS

The findings of the present study revealed that PM10 levels were evident and varied in all sites monitored. The standard was also exceeded in north and south areas and the level of exceedances also varied between the areas.

CHAPTER FIVE

5. DISCUSSION

The results from this study, among the first to describe in a systematic manner the exposures of particulate matter in the Durban municipality, indicate that while levels on average do not exceed national or international standards, exceedances are frequently experienced. In addition, there was considerable variation in exposures throughout the city, with different potential sources.

The municipality median was 42.4$\mu g/m^3$, and the median values recorded in all areas ranged between 40 – 50$\mu g/ m^3$ and showed moderate spatial and temporal differences [1]. This is below the South African standard of 75$\mu g/m^3$ over a 24-hour period.

Table 4 and 5 describes the data set. The number of samples varied across sampling months (table 4) and across sampling sites (table 5). The data was collected during intensive phases and non-intensive phases, as described in annexure 1. During intensive phases samples were collected every day for 3 weeks, resulting in more data and during non-intensive phases samples were collected every sixth day, resulting in a smaller data set. Hence the months included in the intensive phases would have more data as apposed to the months included in the non-intensive phases. This explains the variance across the sampling months. The variance (131 Briardale – 167 Nizam) across sampling sites was due to many factors, including sampling errors and equipment malfunction, for which no data was available. However, the data set was subjected to strict protocols and standard operating procedures, and it passed rigorous Q/A checks as described further in annexure 1. This provides the confidence that the data set is reliable and valid.

Of interest in this study was the presence of differences between a highly industrialized area (south Durban) and an area with minimal industrial activity (north Durban). The findings of the current study did not show any statistical difference in exposure levels. The median levels in north and south were 38.1$\mu g/m^3$ and 45.7$\mu g/m^3$ respectively. These findings are contrary to those reported in other studies investigating differences within micro-systems (different areas within a larger metropolitan area).

The original hypothesis that there will be substantial differences between the industrialized areas south of the city compared with the areas in the north was supported by the findings in several other studies. The study in Kolkata, India reported higher PM10 concentrations for industrial areas than residential areas [24]. The 24 hour average concentrations of PM10 were reported in the range of 68.2 – 280.6$\mu g/m^3$ for residential areas and 62.4 – 401.2$\mu g/m^3$ for industrial areas [24]. The higher PM10 levels at the industrial site was attributed to re-suspension of road dust, soil dust, emissions form traffic and industry. A high regional difference was reported in that study, this similarity was not observed in present study.

Another study that characterized differences between industrialized and residential areas was the Chaulya et al study. This study reported a wide range (102.5μg m^3 to 425.6$\mu g/m^3$) for 24-hour average PM10 concentrations for industrial areas as compared to (40.8$\mu g/m^3$ to 171.9$\mu g/m^3$) for residential areas [20]. Chaulya et al concluded that the impact of industrial activity contributed significantly to the extremely wide range reported for industrial areas. Maximum concentration of PM10 was observed within the industrial areas.

The study by Rodriguez et al also characterized differences between industrialized and residential areas. The results of that indicated PM10 annual average concentrations at the industrial sites (49.5$\mu g/m^3$) were higher than those at the rural residential areas (22.0$\mu g/m^3$) [23]. This study provided a clear indication that PM10 concentrations are higher in areas that were industrially exposed than areas that were not industrially exposed.

There could be several reasons why the findings of the current study differed from these other studies, as well as the hypothesis of the current study.

These are, lack of well documented sources of PM10 emissions in the north areas which were not exposed to industry; it was plausible that the study underestimated the contribution of PM10 emissions from sources such as traffic, burning of bio-fuel, field fires further north and dust intrusions from unpaved areas; the influence of climatic factors such as temperature inversions and impacts on a regional scale.

North (Ngazana) and south (Assegai) recorded extreme values that exceeded 200$\mu g/m^3$. This occurred on 3 occasions. There is no evidence to determine the reasons for these extreme exposures. This could have been due to either traffic, biomass fuels and open field fires (Ngazana) or industrial sources (Assegai). These are typical sources reported in other studies with similar high values. Field fires further north may have also contributed to these extreme values. These varied potential sources for exposure are the most likely reason for the lack of substantial differences between the north and south.

The number of 24-hour PM10 exceedances (163) that was observed was of particular concern. The study expected higher number of exceedances in south Durban, which was exposed to industry, than areas in north Durban, which was not exposed to industry. This was not supported by the data. Exceedances were generally observed across all sites. Although Durban south reported a higher percentage (17.2%) of exceedances, this was marginally higher when compared to the north (15.9%). The highest percentage of exceedances was reported both in the north at Ngazana (24.6%) and in the south at Assegai (26.3 %). This diluted any difference between the areas. Exceedances observed in the current study were similar to other studies. Exceedances may be an important risk factor for adverse health outcomes in community exposures.

One of the salient findings in the Chaulya et al study was that 24 hour PM10 concentrations exceeded the respective NAAQS standard at some residential monitoring sites and at most industrial sites [20]. At least 2 monitoring stations in residential sites reported exceedances above the threshold limit for 24 hours (100$\mu g/m^3$). These were found to vary from 42 to 46 % of the total observations respectively. The 24 hour average PM10 concentration ranged from 102.5$\mu g/m^3$ to 425.6$\mu g/m^3$ among all the monitoring sites.

The percentages of total readings exceeding the 24 hour average threshold limit ($150\mu g/m^3$) for industrial sites, ranged from 6 to 89 %. A coal handling facility in Lakhanpur, an industrial site, contributed significantly to this wide range. The possible sources for these exposures are area sources (mining sites, exposed dump sites, coal handling and stock yards, railway sidings and domestic coal burning), line sources(traffic and unpaved roads) and point sources (mine drilling, blasting, coal loading and unloading) [20].

Although the Karar et al study in Kolkata, India reported higher PM10 concentrations for industrial areas than residential areas [24], the NAAQS was exceeded at both monitoring sites. Approximately 85 % of the overall daily average PM10 data at residential area and 70 % at industrial area exceeded the NAAQS. The high exceedances in residential area were attributed to use of coal as a fuel in nearby small restaurants, construction sites and emissions from solid waste dump site.

In the current study, overall, June experienced the highest PM10 values, in terms of medians ($75.1\mu g/m^3$), extreme values ($266.6\mu g/m^3$) as well as the number of exceedances (90, n=179) As expected this trend continued in May and July. No differences were observed between north and south. This was clearly an indication that the exposures displayed strong seasonality with winter recording the highest levels. Seasonality has been reported in several studies, with higher PM10 levels recorded in the winter months in Southern California [19], in East Spain [21] and in Belgium [22]. The seasonal variation experienced in the current study was consistent with the inversion phenomenon experienced during the winter period. The monthly averages for PM10 from November 2000 to April 2001 as reported in the SPSHS showed fairly constant levels ranging from $24\mu g/m^3$ to $30\mu g/m^3$ and an increase in May 2001 to $55\mu g/m^3$. This study attributed the increase to temperature inversions associated with seasonal changes.

Inversion results in longer residence time of particulates in the atmosphere due low wind speeds, low temperatures and low mixing height. This slows the rate of dilution and dispersion of the pollutant.

The Chit-Ming Wong study reported marked seasonal variation in ambient PM10 in Hong Kong. The lowest levels in PM10 were observed in the warm season and the highest levels were observed in the cool season. This further characterizes the inversion phenomenon. The Karar et al study reported a significant seasonal trend of PM10 using 24 hour average concentrations [24]. For the investigation of seasonal variations of PM10 in that study, the year was divided into three periods, summer (March to June), monsoon (July to October) and winter (November to February). The maximum (401.2 $\mu g/m^3$) daily PM10 concentration was recorded during winter [24]. Higher winter PM10 concentrations were due to low winds, low temperature and low mixing height, which is typical of an inversion episode.

As non-parametric statistics was used to analyze our data, annual median values were used to make comparisons with the annual standard value of 40$\mu g/m^3$ (SANS Code 1929). The annual median values (table 6) at all sites ranged from 34.9$\mu g/m^3$ (Briardale) to 51.4$\mu g/m^3$ (Assegai). The annual median value for south and north was 45.7$\mu g/m^3$ and 38.1$\mu g/m^3$ respectively (table 7). Although the annual median values at Ngazana (42.9$\mu g/m^3$), Nizam (45.9$\mu g/m^3$), Assegai (51.4$\mu g/m^3$), Dirkie Uys (41.5$\mu g/m^3$), Lamont (45.4μg m^3) and overall south (45.7$\mu g/m^3$) exceeded the annual standard value of 40$\mu g/m^3$, statistically these were not significantly different to each other. The results also show that the median PM10 for certain areas were higher than the standard value of 40$\mu g/m^3$, and other sites were near this value, statistically the standard value was not significantly different to the sites. Figures 8 and 9 show that, the annual standard value of 40$\mu g/m^3$ was in all cases inside the inter-quartile range for each site and area, therefore implying no significant difference.

The robustness of the data collected is critical in studies of this nature. The dataset reviewed in this study was subjected to well documented and standardised protocols for quality assurance, data collection and analysis, which provides the confidence that the dataset was reliable and valid.
The percentage of data lost due to either equipment failure or sampling time error is unknown.

However the percentage of data points identified as outliers (34.2%) and extreme values (8.7%) were not excluded from the analysis. Outliers and extreme values were not considered to be problem as non-parametric statistics were used and these data points were included in the study. This provides the confidence that the data was representative of the true exposures experienced by the communities included in the study.

The use of different equipment types (gravimetric sampling and the TEOM) was a limitation of the study. However, resource constraints dictated this decision. To ensure that there was comparability of data across equipment, collocation studies were conducted. These found no substantial differences between equipment type. This approach has been reported by other studies, such as the SPSHS, which used TEOM (Model Series 1400a, Rupprecht & Patashnick, Albany NY) and gravimetric samplers (Partisol Model 2025 Sequential Air Sampler, Rupprecht & Patashnick, Albany NY) to determine PM10 concentrations. The study reported comparison of gravimetric and TEOM data, which showed high correlation (r=0.95). The regression equation relating to the comparison was PM10 (TEOM, $\mu g/m^3$) = 1.0573 x PM10 (filter, $\mu g/m^3$) - 5.2405 [3]. Overall, results indicate good agreement between the two PM10 measurement approaches.

In summary, our study showed that while average levels of exposure in the city are within national and international standards, and that there is limited variation within the city boundaries, exceedances above the standard is not uncommon, and, as expected, is generally seen during the winter months. The absence of differences between north and south clearly suggests that different sources of pollution are evident in the city, with industrial sources in the south, together with traffic, open field fires and biomass burning being potential sources in the north.

CHAPTER SIX

6. RECOMMENDATIONS

6.1 SPECIFIC RECOMMENDATIONS

6.1.1 Source Identification

Appropriate methods, such as emissions inventory, must be developed to identify actual and potential sources of PM10. The inventory must include emissions from industry, traffic, agricultural activities, incineration, various energy sources, domestic activities, and field fires.

6.1.2 Controls for Non Industrial Sources

Control measures for non-industrial sources should target areas such as unpaved roads, arid open spaces, and domestic use of bio-fuels and refuse burning. There are a range of temporary measures available for non industrial sources. The best option is to permanently modify to eliminate dust generation. Modifications should include measures such as covering exposed areas with vegetation, stone or concrete. Dust controls measures must be applied to any area that generates large quantities of dust. Application of dust controls is especially critical in arid areas [27], where exposed soil is more likely to be transported into the receiving environment.

Permanent vegetative covering includes seeding and planting grass to stabilize exposed areas against wind erosion. Existing trees and large shrubs serve as natural barriers against wind blown dust and their growth should be sustained. Top soiling is a method that is recommended when permanent vegetation cannot be established. Top-soiling is a process in which less erosive soil material is applied on top of highly erodible soil [27]. Coarse gravel or crushed stone [27] can also be placed over highly erodible soils.

Irrigation and water spraying suppresses dust generation. The site is sprinkled with water until the surface is wet and the process is repeated [27] as required.

Electrification of low cost and informal housing is important to reduce the domestic use of bio-fuels and wood burning appliances. Electricity should be affordable to avoid dual fuel use, which is the use of electricity and fossil fuel. The necessary infrastructure is required to deliver this service. Realistic time frames with achievable targets, and political and financial commitment is required.

The public must be discouraged against the practice of burning garden and domestic refuse. The public must be encouraged to use proper refuse disposable facilities and methods. To achieve this end public education and awareness programmes are necessary. Law enforcement and monitoring by the authorities is required.

6.1.3 Controls for Industrial Sources

Dust control for industrial activities normally involves mechanical systems designed to reduce dust emissions from in-plant processing activities and material handling. These may include hoods, cyclone collectors, bag-type collectors, filters, negative pressure systems, and mechanical sweeper [27].

Fuel combustion is responsible for significant emissions of PM10. Coal, oil, and natural gas are the most common fuels used. Of these fuels, coal combustion generally results in the highest PM emissions. Fuel substitution can be undertaken as a means of reducing emissions from combustion sources, such as incinerators and industrial boilers. It involves replacing the current fuel with a fuel, which emits less PM10 during the combustion process [28]. Industrial facilities that use coal, which emits high PM10, can substitute with oil or natural gas. Natural gas is a relatively clean-burning fuel and typically results in much less PM10 than oil or coal.

Process modification and optimization can also be an effective means of reducing PM10 emissions. Industrial activities require many individual processes involving simple functions. Material transfer steps can cause fugitive PM10 emissions.
A careful analysis of all process steps may reveal some unnecessary or repetitive steps, which can be eliminated, resulting in fewer fugitive PM10 emissions.
Optimization of industrial equipment and operations includes [28]:

- Limiting the amount of dust available for emissions,
- Improving the arrangement of materials that generate dust,
- Optimizing the process so that less dusty material is used and made vulnerable to air contact.
- Preventing or minimizing leaks within industrial process plants.
- Tuning industrial boilers to achieve more efficient combustion to reduce PM10 that occurs as a result of incomplete combustion.

6.2 SUMMARY

The approach to controlling PM10 must be holistic and must involve all role players in government and industry. Continuous PM10 monitoring and data collection is important to determine long term trends and to undertake source apportionment studies. The benefits of controlling PM10 must be weighed against the health impacts and the cost of treating health aliments caused by PM10 exposure.

ANNEXURE 1: SDHS Data Collection Methodologies

The SDHS includes a health risk assessment as well as an epidemiological study.

The two broad objectives of that study were:

i). To determine health outcomes and other chronic diseases and to determine the relationship between environmental pollution, these health outcomes and the quality of life within south Durban community, particularly among susceptible populations ("the epidemiological study")

ii). To describe the range among ambient exposures and to assess the potential risks posed by such exposures to the health of the community in the Durban South ("the health risk assessment")

1. Site Selection for PM10 Monitoring

Data for the assessment of fluctuations in health outcomes was dependent on continuous monitoring of ambient air pollutants including PM10. The monitoring of pollutants in the SDHS was integrated with the Air Quality Management Systems (AQMS). The eThekwini Municipality commissioned a continuous air quality monitoring network as part of its strategy to deal with air quality issues. One of the major elements of the air quality monitoring network was the AQMS. Monitoring stations were located within schools as this was the focal point of the health surveillance in the SDHS. The location of the monitoring sites was determined by the AQMS for the Durban Metro. This was a critical factor in deciding the selection of the schools. The monitoring sites had to represent the exposure of the study population. Therefore the monitoring sites were located within schools.

In order to ensure that the study sample was representative of the immediate geographic location of the monitoring station, only schools with <15% of pupils from the surrounding communities were selected. Meteorological factors and the location of nearby industries were also considered in school selection. Information pertaining to the health status of students at the school was not included in the selection criteria.

The comparison population was located in Durban north and comprised mainly of residential land use with relatively minimal industrial activity. Therefore this area differed in the profile of air pollutants in the DSIB. This was based on specific information such as data relating to land use planning. This sample strategy enables one to characterize the exposure outcome in the DSIB as well as to differentiate and compare the exposures between the DSIB from other areas in the Durban region.

The following provides a description of the various sampling sites:

Assegai Primary School

Located in Austerville, in close proximity to two major industries (Engen Oil Refinery and Mondi Paper Mill). The school is surrounded by urban residential houses and within a kilometer from the Southern Freeway, a major arterial road. The monitoring site was established on concrete surface approximately 12m from the school's administration block and 20meters (m) from the access road. A high volume sequential sampler was deployed on this site.

Dirkie Uys Primary School

Located in Bluff approximately 1.5 kilometers away from the Engen Refinery. The school is situated adjacent to Tara Road, although not a national route, the traffic on this road is known to be high. Heavy duty articulated vehicles also make use of this road. The school is surrounded by residential houses with no informal settlements nearby. The monitoring site was established on a large grassy field approximately 12m from school buildings and 160m from the access road. A high volume sequential sampler was used at this site.

Nizam Primary School

Located in Merebank approximately 3 kilometers from Engen Refinery and Mondi Paper Mill. The school is situated in close proximity to Travencore Drive which experiences high traffic volumes. The school is surrounded by formal residential houses. The monitoring site was established on a tarred surface close to a grass bank. A low volume Partisol (2000) sampler was used at this site.

Entuthukweni Primary School

Located in Lamontville. The school is surrounded by an informal settlement. The informal settlements are reliant on biomass fuels; this could be a major source for PM10 in the area. The school is also situated adjacent to the N2 outer ring road. This road is one of the busiest roads within the eThekwini region and serves as major national road freeway. The school is also located in close proximity to major industries such as Sapref oil and Engen oil refineries, and Mondi paper mill. The site was established on a tarred surface approximately 3m from a low lying grassed and sandy field. A high Volume sequential sampler was used at this site.

Briardale Primary School

Located in Newlands West. The school is secluded from industries. The nearest major road is approximately 500m away. There are no informal settlements near the school. The monitoring site was established on the grassy field approximately 15m from the administration block and classrooms. A medium volume sequential sampler was used at this site.

Ferndale Primary School

Located in Newlands East. There are no industries near the school. The nearest major road is approximately 600m away. There are no informal settlements near the school. The monitoring site was established in the parking lot of the school, on a grassy patch approximately 10m from the road and 15m from the administration block. A TEOM and medium volume sequential samplers were used at this site.

Ngazana Primary School

Located in Kwa–Mashu. The school is surrounded by formal low cost housing. There are no major roads close to the school. The monitoring site was established on a grass field in the centre of the school. A medium volume sequential sampler was used at this site.

2. Data Collection

PM10 in ambient air was measured from May 2004 to September 2005 over a 24-hour period in the SDHS. In principle an electrically powered air sampler draws ambient air at a constant volumetric flow rate into a specifically shaped inlet and through an inertial particle size separator where the suspended particulate matter in the PM10 size range is separated on a filter media over the specified period [29]. The volumetric flow rate was predetermined and varied according to the specific requirements of the sampler.

Different filters were used during sampling to comply with the manufacture's specification of the different sampling instruments and to accommodate other pollutants that formed part of the broader SDHS. Filters used were Quartz filter; Teflon filter and Glass fibre filter, which are approved for PM10 sampling. PM10 sampling programme for the SDHS was undertaken to form part of the broader health risk assessment. The PM10 data was used to assess fluctuations in health outcomes within the study populations. In the SDHS lung function spirometric test was conducted on all school children participating in the three week intensive data collection sessions. PM10 data was required for this purpose during the three week cycle (intensive phase). Therefore the PM10 sampling was conducted during intensive phases (every day for three weeks) and non-intensive phases (every sixth day). To collect data everyday during the non-intensive phase would not provide any additional value to the study. The collection of samples every sixth day is an approved method by the US-EPA. The sampling period was over 24 hours (8:00am to 8:00am). Correct sample filters rates and filter handling, documentation, and analysis were fundamental for obtaining valid data during the SDHS.

The filters were conditioned in a temperature and humidity controlled environment, typically between 20°C and 50°C relative humidity, for at least 24-hours before and after exposure. The filters were accurately weighed using an analytical microbalance that has been calibrated using US-EPA methods.

Filters were weighed prior to and after sampling, and after conditioning filters for several days in a controlled temperature (25° C) and humidity (50%). Gravimetric measurements were reproducible and consistent, based on repeated measurements of a QA filter and replicates. Daily QA checks included repeated weighing of a QA blank filter and field blank filter. The filters were weighed three times and the concentrations were calculated using the average weights.

In order to compare the performance of the five different types of PM samplers against a recognized reference method, a collocation (side by side) study was undertaken. Collocation is the placement of a sampler, known as the test sampler, near a second sampler known as the reference sampler. The reference sampler is considered to provide accurate results, based on its recognized and well documented performance. Comparison of results from the samplers was used to estimate the precision and bias of the test sampler, thus allowing for the comparison of results from the different types of PM measuring instruments deployed in the study [30]. For the purposes of the SDHS, the Partisol 2025, a recognized US-EPA Reference Method, was designated as the reference method. The PM collocation study was conducted at the Water Reservoir in Wentworth, Durban south. This was the site of an existing monitoring station, and the location of a TEOM continuous PM monitor.

This site was chosen as it represents the community's exposure. According to the collocation study results there was an acceptable correlation (0.90 to 0.92) between all the air monitors and the reference method. This study also did not observe systematic biases between filter types. The data collected represented the local community's risk of exposure to PM10. This provided the research team with the confidence that the variation across the different equipment was marginal and would produce valid data when deployed in the different monitoring sites.

3. Data Processing and Quality

Data capture rates varied across the monitoring sites and by monitoring type. The TEOM had capture rates exceeding 80%. Filter-based samples at the schools were collected daily during the intensive phases, and less frequently, on an every sixth day schedule. The number of 24-hour filter samples at the sampling sites ranged from 131 at Briardale to 167 at Nizam.

4. Data management

An electronic database was created when results were obtained after laboratory analysis. The data was captured using Microsoft Excel. All data was subjected to validity and accuracy checks against paper records. A separate database was maintained for metrological conditions.

5. Quality Assurance and Quality Control (QA/QC)

The SDHS developed a comprehensive QA/QC plan, which was based on the US-EPA Quality Assurance Handbook for Air Pollution Measurement Systems. QA was achieved by developing a system of activities to ensure that measurements met defined standards of quality with stated levels of confidence. The QA plan included defined monitoring objectives, quality control procedures and quality assessment.

QC included protocols for site operation and equipment maintenance; protocols for data inspection, review, validation, and usage. Quality assessment included schedules for audits and reports. All field personnel in the SDHS were familiar with environmental field measurement techniques and operation of equipment according to procedures as specified in the operation manual. In addition appropriate training for laboratory and field personnel was undertaken which included operating PM10 sampler, calibrating, temperature, pressure, flow rate and relative humidity in the field.

6. Laboratory Techniques

Standard operating procedures were developed for filter conditioning and filter weighing in the laboratory. In order to avoid filters being contaminated with trace metals, Teflon tweezers were used, as apposed to metal tweezers. The filters were conditioned in a controlled environment in agency laboratory for a minimum of 24-hours prior to weighing and it was conditioned in the same controlled environment in which the balance was kept.

The controlled environment was designed to achieve the following:

- Mean temperature : 20 – 30°C
- Temperature control : ±2 °C over 24 hours
- Mean humidity : 50 percent relative humidity
- Humidity control : ±5 % relative humidity over 24-hours
- Conditioning time : not less than 24-hours

Each filter was weighed three times using and analytical micro-balance readable TO 10 µg (Ohaus 11378-050). Daily QA checks included repeated weighings of QA blank filters and field blank filters. Concentrations were calculated using the average weights and the average of pre-and post-sampling flow rates multiplied by the elapsed time. Both pre- and post- sampling weighing was carried on the same balance and by the same analyst in order to reduce the chances of measurement bias. An effective technique was used to neutralize static changes on the filter.

The pre- sampling weighing was carried out within 30 days of the sampling period and the post- sampling weighing was carried out within 10 days after the end of the sampling period. Field sample blanks and laboratory blanks were used for QC checks. New filters were placed in the conditioning environment immediately upon arrival and stored there until the pre- sampling weighing.

ANNEXURE 2: Fields used in data collection sheet

Date of sample

Site reference number

Sampling month

Area (north/south)

PM10 concentration

Standard Exceeded (yes/no)

ANNEXURE 3: Ethics Approval Letter

UNIVERSITY OF
KWAZULU-NATAL

Research Office
BIOMEDICAL RESEARCH ETHICS ADMINISTRATION
Nelson R Mandela School of Medicine
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18th October 2006

Mr G Moodley
Department of Community Health, Public Medicine
Nelson R Mandela School of Medicine
University of KwaZulu-Natal

PROTOCOL: **A comparative study to investigate the ambient of particulate matter (PM10) in industrial exposed and non-industrial exposed communities. Mr. G. Moodley. Department of Community Health, Public Medicine EXP040/06**

EXPEDITED APPLICATION

Dear Mr. G. Moodley

This letter serves to notify you that at a full sitting of the Biomedical Research Ethics Committee meeting held on **17th October 2006,** the Committee RATIFIED the sub-committee's decision to approve the above study.

Yours sincerely

SURAIYA BUCCAS
Ethics Research Administrator

SB/sn

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